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EUROPEAN PATENT APPLICATION

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(54) Fuel assembly for nuclear reactor.

(57) Provided are fuel assemblies each having an outer peripheral zone and a central zone surrounded by the former and adapted to be loaded in a reactor core, the fuel rods therein being arrayed in a certain pattern such that the fuel rods (1) disposed in the outer peripheral zone have a smaller fuel volume than that of those (2) disposed in the central zone. Such a fuel assembly offers a suitable distribution of local power output as well as a high degree of burn-up.

FIG. 1

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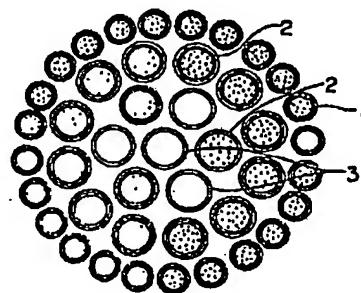
FUEL ASSEMBLY FOR NUCLEAR REACTOR

1 BACKGROUND OF THE INVENTION:

.The present invention relates to a fuel assembly adapted to be loaded in the core of a nuclear reactor.

In a reactor core, a multiplicity of fuel

5 assemblies are arrayed in a predetermined pattern. Since moderators such as D_2O and H_2O are filled in the space between adjacent fuel assemblies, the density of neutrons in the vicinity of the outer peripheral zone of each fuel assembly is high, so that the local power output of

10 each fuel assembly is high in the outer peripheral zone and is considerably low in the central zone thereof.

In order to equalize the local power output, a conventional fuel assembly is arranged such that fuel rodes with a high fuel enrichment factor are disposed in

15 a zone having a low thermal neutron flux density, while fuel rods with a low fuel enrichment factor are disposed in a zone having a high thermal neutron flux density.

A recent tendency of light water reactors and heavy water reactors is to prolong the operating cycle

20 from twelve months to 15 months by improving the capacity utilization ratio of the reactor. To this end, it is necessary to increase enrichment. Consequently, the distribution of density of fissile material contained in the reactor core becomes considerably uneven, and the

25 thermal neutron flux density also varies locally in the

1 reactor core and fuel assemblies. As a method of **0196655**

equalizing the local power output in the core and to

minimize the maximum value of local power in the core as

practically as possible, a method is generally taken in

5 which the enrichment factor of fuel disposed in a zone

having a high thermal neutron flux density is set such as

to be lower than that of fuel disposed in a zone having a

low thermal neutron flux density, thereby equalizing

local variations in the thermal neutron flux density.

10 As described above, in order to equalize the distribution

of local power in fuel assemblies, a method is taken

whereby the enrichment of fuel rods disposed in the outer

peripheral zone having a high thermal neutron flux density

is decreased, while the enrichment of fuel rods disposed

15 in the central zone is increased.

However, if the fuel enrichment factor is

increased to prolong the operating cycle, variations in

the thermal neutron flux density becomes noticeable, and

the thermal neutron flux becomes very high in the outer

20 peripheral zone of each fuel assembly, while it becomes

extremely low in the central zone. Namely, the local

power output in the outer peripheral zone of each fuel

assembly becomes maximum, and if the fuel enrichment

factor is increased, the maximum local power output also

25 increases. In order to prevent the maximum local power

output from increasing, it becomes necessary to set the

difference between the enrichment of fuel disposed in

the outer peripheral zone and that of fuel disposed in

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1 the central zone to a very large level. For instance, in fuel assemblies for a nuclear reactor operated with a long-term operating cycle of one year or longer, an attempt is made to equalize the power output per fuel

5 rod of a fuel assembly by reducing the enrichment of fuel rods disposed in the outer peripheral zone to approximately one half of that disposed in the central zone.

Nevertheless, since there is the problem that it is necessary to inhibit the thermal stress of fuel

10 rods with respect to cladding pipes, it is impossible to unlimitedly increase the maximum local power output per fuel rod. Hence, the enrichment per fuel rod cannot be set to an extremely high level. As a result, to equalize the distribution of power output, fuel rods whose fuel

15 enrichment is average or below are disposed in the zone having a high neutron flux density that contributes substantially to nuclear fission. Consequently, it becomes impossible to effectively burn up the fissile material, which is the fuel.

20 To overcome the aforementioned problems, a fuel assembly for a light water reactor has been proposed in which the power output per fuel rod is reduced by making the diameter of fuel rods small so as to reduce the temperature of fuel, and, as the same time, a greater

25 volume of fissile material is disposed in the zone having a high thermal neutron flux density. If the diameter of fuel rods is simply made small, however, the fabrication of fuel assemblies becomes complicated, since the number

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1   of fuel rods increases, and also since the diameter of

fuel rods becomes small. In addition, the volumetric

share of materials other than fissile material such as

cladding pipes increases, thereby giving rise to such

5   problems as an increase in the volume of wasteful

absorbents for neutrons.

In addition, the specification of Japanese

Patent Unexamined Publication No. 40187/1978 discloses

an arrangement in which fuel rods are arrayed in the

10   shape of a triangular or square lattice inside each

pressure tube of a pressure tube type reactor, and small-

diameter fuel rods are disposed in nonuniform and

relatively large spaces between the inner surfaces of

pressure tubes and the array of fuel rods in the outer

15   peripheral layer. This arrangement disclosed in the

specification of Japanese Patent Unexamined Publication

No. 40187/1978 is an attempt to make uniform the interval

between the array of fuel rods and the inner wall of

pressure tubes so as to set the flow rate of light water

20   flowing therein to a fixed level. With this arrangement,

however, two types of fuel rods comprising a set of

large-diameter fuel rods and another set of small-diameter

fuel rods are mixed in the zone having a high neutron

flux density, i.e., the outer peripheral zone. In such

25   an arrangement, it is difficult to equalize the distribu-

tion of local power output.

Furthermore, in the specification of U. S.

Patent No. 3132076, a fuel assembly for a boiling water

1 reactor for the purpose of equalizing the distribution
of power output is proposed. This fuel assembly is
arranged such that slit-like channels for light water
are provided between the arrays of fuel rods, each array
5 being disposed in the shape of a square lattice, and the
ratio between light water and fuel is made large so as
to equalize the distribution of power output. According
to this method, it becomes possible to attain the equali-
zation of power output to some extent, but the amount
10 of fuel decreases by the portion in which light water
channels are provided. However, no consideration is
given in that specification as to how the output per fuel
rod can be increased by taking that situation into account.

Consideration will be given hereinafter of the
15 linear heat rating per unit length of a fuel rod by
paying attention to individual fuel rods of each fuel
assembly.

Assuming that the zone having a high thermal
neutron flux density contributing to nuclear fission is
20 H, and that the zone having a low thermal neutron flux
density is L, the linear heat rating of each fuel rod
in the respective zones can be given by the following
formulae (1) and (2):

$$P(H) = N(H) \times \sigma_f(L) \times \phi(H) \times V \quad \ldots\ldots \quad (1)$$

$$P(L) = N(L) \times \sigma_f(L) \times \phi(L) \times V \quad \ldots\ldots \quad (2)$$

Where P(H): linear heat rating (W/cm) of fuel in a fuel

rod in the zone of a high neutron flux density H

$N(H)$: density of fissile material (pc/cm^3) in a fuel rod in the zone of a high neutron flux density H

$\sigma_f(H)$: microscopic fission cross section (cm^2) of in the zone of a high neutron flux density H

$\phi(H)$: neutron flux density (thermal neutron/$cm^2 \cdot sec$) in the zone of a high neutron flux density H

$P(L)$: linear heat rating (W/cm) of fuel in a fuel rod in the zone of a low neutron flux density H

$N(L)$: density of fissile material (pc/cm^3) in a fuel rod in the zone of a low neutron flux density L

$\sigma_f(L)$: microscopic fission cross section (cm^2) of in the zone of a low neutron flux density L

$\phi(L)$: neutron flux density (thermal neutron/$cm^2 \cdot sec$) in the zone of a low neutron flux density L

V: fuel volume (cm^3)

From the premise, it follows that $\phi(H) > \phi(L)$.

With respect to the power output of fuel rods, the maximum power output should desirably be low. For this reason, it is necessary to decrease a power peaking

1 factor so that the power output of fuel rods is brought

close to the average power output. This means that P

(H) and p (L) in Formulae (1) and (2) should be brought

as close to each other as possible.

5   If the power output of fuel rods in the zone

of a high thermal neutron flux density and the zone of

a low thermal neutron flux density is assumed to be

P_0 (H) and P_0 (H), respectively, a method has conventional-

ly been adopted to change an enrichment factor N in

10 response to the magnitude of the thermal neutron flux

so that P_0 (H) $\simeq$ P_0 (L). In other words,

$$P_0 \text{ (H)} = N_0 \text{ (H)} \times \sigma_{f0} \text{ (H)} \times \phi_0 \text{ (H)} \times V_0 \quad .. \quad (3)$$

$$P_0 \text{ (L)} = N_0 \text{ (L)} \times \sigma_{f0} \text{ (L)} \times \phi_0 \text{ (L)} \times V_0 \quad .. \quad (4)$$

$$N_0 \text{ (H)} < N_0 \text{ (L)} \quad .... \quad (5)$$

$$\phi_0 \text{ (H)} > \phi_0 \text{ (L)} \text{ (shown in Fig. 7)} \quad .... \quad (6)$$

In view of the foregoing reason, fuel of

low-density fissile material, i.e., fuel of a low

enrichment factor, is disposed in the zone of a high

15 thermal neutron flux density. Thus, as described earlier,

it has been very difficult to improve the degree of

burn-up without increasing the maximum local power of

the fuel rods of fuel assemblies and to equalize the local

power of fuel assemblies.

20   A general object of the present invention is

to provide a fuel assembly which is capable of attaining

a high degree of burn-up without accompanying an increase

1   in the maximum local power and of equalizing the

distribution of local output.

According to the present invention, there is

provided a fuel assembly in which the fuel volume V of

5   a fuel rod is adjusted so that P (H) ≒ P (L) where P (H)

is the fuel power density of a fuel rod in the zone of

a high neutron flux density, and P (L) is the fuel output

density of a fuel rod in the zone of a low neutron flux

density.

10   In other words, if, in

$$P\ (H) = N\ (H) \times \sigma_f\ (H) \times \phi\ (H) \times V\ (H) \quad \ldots \ (7)$$

and

$$P\ (L) = N\ (L) \times \sigma_f\ (L) \times \phi\ (L) \times V\ (L) \quad \ldots \ (8)$$

it is assumed that

$$N\ (H) = N\ (L) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (9)$$
$$\phi\ (H) > \phi\ (L) \ \text{(shown in Fig. 7)} \quad \ldots\ldots\ldots \ (10)$$
$$V\ (H) < V\ (L) \ \text{(shown in Fig. 7)} \quad \ldots\ldots\ldots \ (11)$$

Then, it becomes possible to bring the values of P (H)

and P (L) close to each other.

15   Specifically, the present invention provides a

fuel assembly for a nuclear reactor, adapted to be loaded

1. in a reactor core, wherein a plurality of fuel rods are

disposed in a predetermined pattern in the cross-sectional

direction of the fuel assembly, the fuel rods including

those that are arrayed in the outer peripheral zone of

5 the fuel assembly, those that are arrayed in the inter-

mediate zone thereof, and those that are arrayed in the

central zone thereof, the fuel rods having a substantially

fixed factor of fuel enrichment, and each fuel rod arrayed

in the outer peripheral zone has a fuel volume smaller

10 than that of each fuel rod arrayed in the intermediate

zone and the central zone.

Furthermore, according to the arrangement of

an embodiment of the present invention, there is provided

a fuel assembly for a nuclear reactor, adapted to be

15 loaded in a reactor core, wherein a plurality of fuel

rods are disposed in a predetermined pattern in the

cross-sectional direction of the fuel assembly, the fuel

rods including those that are arrayed in the outer

peripheral zone of the fuel assembly, those that are

20 arrayed in the intermediate zone thereof, and those that

are arrayed in the central zone thereof, the fuel rods

having a substantially fixed factor of fuel enrichment,

and each fuel rod arrayed in the outer peripheral zone

having a diameter smaller than that of each fuel rod

25 arrayed in the intermediate zone and the central zone.

The above and other advantages of the invention

will become more apparent in the following description

and the accompanying drawings.

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1 words, 15 large-diameter fuel rods 2 are arrayed in the

   intermediate and central zones, while 24 small-diameter

   fuel rods 2 are arrayed in the outer peripheral zone in

   this embodiment. The large-diameter fuel rods 2 disposed

5 in the intermediate and central zones have an outer

   diameter of approximately 15.7 mm, and about 13.6 mm-

   diameter fuel pellets are loaded therein, respectively.

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Table 1

Fuel layer	No. of fuel rods	Diameter of fuel pellets (mm)	Outer diameter of clad pipe (mm)	Weight of fissile material
Central zone	3	13.6	15.7	0.3 wt.% ^{235}U (depleted uranium)
Inter-mediate zone	12	13.6	15.7	3.0 wt.% $P_u(f_{ia})$ $(P_u MOS)^*$
Outer peripheral zone	24	9.6	11.2	3.0 wt.% $P_u(f_{ia})$ $(P_u MOS)^*$
Total fuel	39	-	-	0.62 wt.% ^{235}U + 2.4 wt.% $P_u(f_{ia})$

* Plutonium is mixed in natural uranium oxides.

(However, it is also possible to use depleted uranium.)

1   In addition, four central support rods 3 for
supporting fuel spacers are disposed in the central
portion of the fuel assembly. Small-diameter fuel rods
1 in the outer peripheral zone have an approximately 11.2
5 mm outer diameter, and fuel pellets having an outer
diameter of about 9.6 mm are loaded therein, respectively.
The overall length of the fuel pellet is about 3,700 mm,
and if the electric power of a nuclear reactor is
assumed to be 600,000 kW, the number of pressure tubes
10 required is about 650. As a coolant, light water or
heavy water is employed. The fuel assembly shown in
Fig. 1 includes fuel rods, central support rods, fuel
spacers for supporting fuel rods that are not shown, and
upper and lower templates. The central support rods play
15 the role of allowing the coolant to flow through a flow
section, and the coolant flows slowly through the inside
of the supporting rods. According to the embodiment
shown in Fig. 1, the number of large-diameter fuel rods
is 15. To adjust the weight of fuel and equalize the
20 output distribution, several fuel rods among the fuel rods
disposed in the intermediate and central zones may also
be made into coolant rods in which the coolant flows
slowly without fuel pellets loaded therein.

As fuel for the fuel assembly shown in Fig. 1,
25 it is possible to use slightly enriched uranium oxide
fuel, or a fuel mixture of uranium oxide and plutonium
oxide fuel. In the embodiment shown in Fig. 1, fuel
material which is enhanced with 3.0 wt% fissile plutonium

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1 added in the form of plutonium oxide to natural uranium

oxide is employed for the large-diameter fuel rods 2.

As for the three fuel rods in the central zone, depleted

uranium fuel is used. This 3.0 wt% can be expressed by

5 the following formula:

$$3.0 \text{ wt\%} = \frac{^{239}P_u + ^{241}P_u}{^{235}U + ^{238}U + ^{239}P_u + ^{240}P_u + ^{241}P_u + ^{242}P_u}$$

(wt% of
fissile
plutonium)

Fig. 2 shows a conventional fuel assembly in

which fuel rods have the same diameter as those of the

large-diameter fuel rods of the fuel assembly of this

embodiment, and the details of construction of the

10 conventional fuel assembly are shown in Table 2 for the

sake of comparison.

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Table 2

Fuel layer	No. of fuel rods	Diameter of fuel pellets (mm)	Outer diameter of clad pipe (mm)	Weight of fissile material
Central zone	6	13	15	3.6 wt.% $P_u(f_{ia})$ (P_uMOS)*
Intermediate zone	12	13	15	3.6 wt.% $P_u(f_{ia})$ (P_uMOS)*
Outer peripheral zone	18	13	15	1.2 wt.% $P_u(f_{ia})$ (P_uMOS)*
Total fuel	36	-	-	0.7 wt.% ^{235}U + 2.4 wt.% $P_u(f_{ia})$

* ... Plutonium is mixed in natural uranium oxides.

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1   Fig. 2 is a conventional fuel assembly for a

pressure tube type reactor, which is arranged such that

36 fuel rods having the same diameter are bundled

together.   One support rod 8 for supporting fuel rods

5 by means of fuel spacers is disposed in the central

portion of the fuel assembly.   A comparison of character-

istics between the embodiment of the present invention

shown in Fig. 1 and the conventional fuel shown in Fig.

2 is given in Table 3 below.

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Table 3

Item		Fig. 1 (Embodiment of this invention)		Fig. 2 (Conventional fuel)
Dia of fuel rod (mm)	Central and intermediate zones	15.7 mm		approx. 15 mm
	Outer peripheral zone	11.2 mm		
Weight of fuel per assembly (effective length: 3,700 mm) (kg)		approx. 170 kg		approx. 170 kg
Weight of fissile material per assembly (kg)	^{235}U	approx. 0.9 kg		approx. 1.0 kg
	$P_u(f_{ia})$	approx. 3.6 kg		approx. 3.5 kg
Weight percent of fissile material (wt%)	^{235}U	approx. 0.62 wt%		approx. 0.7 wt%
	$P_u(f_{ia})$	approx. 2.4 wt%		approx. 2.4 wt%
Burn-up degree (MWd/t)		approx. 38000 MWd/t		approx. 30000 MWd/t
Local power peaking factor		approx. 1.09 (fuel in outer peripheral zone)		approx. 1.13 (fuel in outer peripheral zone)
Maximum linear heat rating (W/cm)		approx. 430 W/cm		approx. 490 W/cm

1   As shown above, in the case of the fuel assembly according to the embodiment of the present invention shown in Fig. 1, in which the plutonium enhancement is set such as to be identical with that of the conventional

5   fuel, the weight of uranium 235 was found to be slightly small, but the burn-up degree was approximately 38,000 MWd/t. Thus, it can be seen that the fuel assembly of this embodiment is capable of increasing the burn-up degree by about 8000 MWd/t as compared with approximately

10 30,000 MWd for the conventional fuel. The local power peaking factor in the embodiment shown in Fig. 1 was about 1.09. With respect to the maximum linear heat rating, in a case where 650 pressure tubes were employed and the two types of fuel were used for a reactor generat-

15 ing a thermal output of 1,950 MW, the maximum linear heat rating of the conventional fuel shown in Fig. 2 was 490 W/cm, whereas, in the case of the embodiment of the present invention shown in Fig. 1, the maximum linear heat rating decreased to approximately 430 W/cm, which

20 was attributable to an increase in the number of fuel rods per fuel assembly to 39 as well as the advantage that the aforementioned local were peaking factor was substantially reduced to approximately 430 W/cm.

     Referring next to Figs. 3 and 4, description

25 of another embodiment of the present invention will be made hereinafter.

     Fig. 3 is a cross-sectional view of a fuel assembly according to another embodiment of the present

1   invention.   0196655

        The fuel assembly shown in Fig. 3 is adapted

    to be loaded in a pressure tube having an inner diameter

    of approximately 120 mm, and the details of its structure

5   are shown in Table 4. As for fuel rods, 12 large-

    diameter fuel rods 2 are employed for the central zone,

    and 24 small-diameter fuel rods 1, for the outer peripheral

    zone.

Table 4

Fuel layer	No. of fuel rods	Diameter of fuel pellets (mm)	Outer diameter of clad pipe (mm)	Weight of fissile material
Central zone	12	14.2	16.5	2.8 wt.% $P_u(f_{ia})$ $(P_u MOS)$*
Outer peripheral zone	24	10.0	12.0	2.8 wt.% $P_u(f_{ia})$ $(P_u MOS)$*
Total fuel	36	-	-	0.7 wt.% ^{235}U + 2.8 wt.% $P_u(f_{ia})$

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1 In addition, further four large-diameter circular

tubes 4 are disposed in the central zone. The cladding

pipes of these fuel rods and the central circular pipes

4 are all made of a zirconium alloy. The large-diameter

5 fuel rods 2 in the central zone have an outer diameter

· of approximately 16.5 mm, and fuel pellets having an

outer diameter of approximately 14.2 mm are loaded in

them. The 24 small-diameter fuel rods 1 in the outer

peripheral zone have an outer diameter of approximately

10 12 mm, and fuel pellets having an outer diameter of

approximately 10 mm are loaded in them.

The fuel material and coolant employed in the

fuel assembly shown in Fig. 3 are the same as those

employed in the embodiment shown in Fig. 1. In the

15 embodiment shown in Fig. 3, fuel material is used which

is enhanced with about 2.78 wt% fissile plutonium added

in the form of plutonium oxide to natural uranium oxide

fuel.

With respect to the coolant flowing in the

20 central circular tube 4 shown in Fig. 3, its flow rate

is held to a small level in such a manner that a pressure

loss does not become high although the coolant is allowed

to flow. Fig. 4 illustrates the longitudinal configura-

tion of the fuel assembly shown in Fig. 3. The fuel

25 assembly is arranged such that small transverse holes 13,

14 serving as inlets and outlets for the coolant are

provided in the upper and lower portions of the central

circular tube 4 in Fig. 4.

1   A comparison between the fuel of the embodiment
of the present invention shown in Fig. 3 and the con-
ventional fuel shown in Fig. 2 is given in Table 5 below.

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Table 5

Item	Fuel		Fig. 3 (Embodiment of this invention)	Fig. 2 (conventional fuel)
Dia. of fuel rod (mm)	Central zone		16.5 mm	approx. 15 mm
	Outer peripheral zone		12.0 mm	
Weight of fuel per assembly (effective length: 4,000 mm) (kg)			approx. 155 kg	approx. 180 kg
Weight of fissile material per assembly (kg)	235_U		approx. 0.95 kg	approx. 1.1 kg
	$P_u(f_{ia})$		approx. 3.8 kg	approx. 3.8 kg
Weight percent of fissile material (wt%)	235_U		approx. 0.7 wt%	approx. 0.7 wt%
	$P_u(f_{ia})$		approx. 2.8 wt%	approx. 2.4 wt%
Burn-up degree (MWd/t)			approx. 41,000 MWd/t	approx. 30,000 MWd/t
Local power peaking factor			1.07 (central zone) 0.95 (Outer peripheral zone)	1.13 (our peripheral zone)

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Table 5 (Cont'd)

Max. linear heat density (W/cm)	approx. 460 W/cm (central zone)	approx. 490 W/cm (outer peripheral zone)
Max. thermal flux (W/cm^2)	approx. 109 W/cm^2 (outer peripheral zone)	approx. 109 W/cm^2 (outer peripheral zone)

1   As shown in Table 5, in the case of the fuel

of the embodiment of the present invention shown in Fig.

3, the weight of uranium 235 per fuel assembly was

slightly small as compared with the conventional fuel.

5   Even if the weight of fissile plutonium is made identical,

its burn-up degree was approximately 41,000 MWd/t, and

it hence becomes possible to improve the burn-up degree

by about 11,000 MWd/t (about 37%) as compared with about

30,000 MWd/t for the conventional fuel. In the case of

10   the conventional fuel, it has been necessary to replace

120 fuel assemblies per year in a nuclear power plant

generating an electric power of 600,000 kW, whereas, in

the case where the fuel of the embodiment shown in Fig.

3 is used, only 100 fuel assemblies may be replaced.

15   This translates into a reduction of 20 fuel assemblies

per year, which means that 17% fuel can be conserved.

In addition, during the initial stage of burn-up according

to the embodiment shown in Fig. 3, the local power peaking

occurred in the fuel in the central zone, and its factor

20   was approximately 1.07. With the conventional fuel, the

local power peaking occurred in the outer peripheral zone,

and its factor is approximately 1.13. Consequently, in

the case of the conventional fuel, the maximum thermal

flux occurred in the outer peripheral zone during the

25   initial stage of burn-up and its value was approximately

109 W/cm_2. On the other hand, in the case of the

embodiment of the present invention shown in Fig. 3,

the maximum thermal flux occurred in the outer peripheral

1 zone during the initial stage of burn-up, and, despite

the fact that small-diameter fuel rods were employed in

that zone, the value of the maximum thermal flux was

approximately 109 W/cm^2, which is identical with that of

5 the conventional fuel. In addition, in the case of the

conventional fuel, the maximum linear heat rating

occurred in the outer peripheral zone and was approximately

490 W/cm, whereas, in the case of the embodiment shown

in Fig. 3, the maximum linear heat rating occurred in

10 the central zone and was about 460 W/cm, representing a

reduction of about 6%.

Referring now to Fig. 5, description will be

made of an application of the present invention to a

light water reactor.

15 Fig. 5 is a cross-sectional view of a fuel

assembly in which the present invention is applied to a

boiling light water reactor. The fuel assembly shown in

this drawing employes 36 small-diameter fuel rods 1 in

the outer peripheral zone, 36 large-diameter fuel rods

20 2 in the central and intermediate zones, and three fuel

rods 5 disposed adjacent to a control rod and having the

smallest diameter. Each of the small-diameter fuel rods

1 has an outer diameter of about 10 mm, and fuel pellets

having a diameter of about 8.1 mm are loaded in them.

25 Reference numeral 14 denotes a cross-shaped control rod.

Each of the large-diameter fuel rods 2 has an outer

diameter of about 13.2 mm, and fuel pellets having a

diameter of about 11.3 mm are loaded in them. Each of

1 the three fuel rods having the smallest diameter has an **0196655**

outer diameter of about 9 mm, and fuel pellets having a

diameter of about 7.4 mm are loaded in them. Although,

in Fig. 5, fuel rods of three types of outer diameter

5 are used, it is possible to increase or decrease the

number of types of the outer diameter depending on the

rate of variations in the thermal neutron flux density

and the need for equalizing the output distribution.

Furthermore, it is also possible to make a part of the

10 fuel rod a water rod as in the case of fuel for a

conventional boiling water reactor.

A comparison between the fuel assembly shown

in Fig. 5 and the conventional fuel for a boiling light

water reactor is shown in Table 6 below.

Table 6

Item	Fuel		Fig. 5 (Embodiment of the invention applied to BWR)	Conventional fuel for BWR
Dia of fuel rod (mm)		adjacent to control rod	approx. 9 mm (3 pcs.)	approx. 12.5 mm
		outer peripheral zone	approx. 10 mm (33 pcs.)	
		central and intermediate zones	approx. 13.2 mm (36 pcs.)	
Weight of fuel per assembly (kg)			approx. 200 kg	approx. 200 kg
Weight of fissile material per assembly ^{235}U (kg)			approx. 4.8 kg	approx. 4.8 kg
Weight percent of ^{235}U (wt%)			2.7 wt% (identical)	2.7 wt% (average)
No. of types of enrichment of ^{235}U			1	4
Burn-up degree (MWd/t)			32000 MWd/t	29500 MWd/t

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1   As shown in Table 6, in the case of the fuel

in the embodiment shown in Fig. 5, although the weight

of fuel and the weight of uranium 235 are identical as

those of the fuel for a conventional boiling light water

5   reactor, the burn-up degree became about 32,000 MWd/t

in contrast to about 29,500 MWd for the conventional fuel.

Thus, it can be seen that the burn-up degree can be

improved by 2,500 MWd/t (i.e., 10%).

Although only one type of uranium enrichment

10   factor was adopted in the embodiment shown in Fig. 5,

it is also possible to change the enrichment factor in

the radial or axial direction of the fuel assembly so

as to effect a further equalization of the output

distribution.

15   Referring now to Fig. 6, description will be

made of an application of the present invention to a

pressurized light water reactor.

Fig. 6 is a cross-sectional view of a fuel

assembly in which the present invention is applied to a

20   pressurized light water reactor. The fuel shown in Fig.

6 is pressurezed water-type fuel employing 17 by 17 rows

of fuel rods, in which small-diameter fuel rods 1 are

employed for 66 fuel rods in the outer peripheral zone

and 100 fuel rods adjacent to control rods 7, while large-

25   diameter fuel rods 2 are employed for the remaining 98

fuel rods. In addition, this fuel assembly has 25 control

rod guide pipes 6. The control rod guide pipes 6 are

adapted such that the control rods 7 are capable being

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1 driven therein. Each of the small-diameter fuel rods

2 has an outer diameter of about 9.4 mm, and fuel pellets

having a diameter of about 8.0 mm are loaded therein.

Each of the large-diameter fuel rods 2 has an outer

5 diameter of ablut 10.6 mm, and fuel pellets having a

diameter of about 9.3 mm are loaded therein.

According to the embodiment shown in Fig. 6,

it becomes possible to equalize the distribution of the

local output inside the fuel assembly, and is also

10 possible to reduce the maximum linear heat rating. In

addition, since the diameter of the fuel rods adjacent

to the control rods is made small, the linear heat

rating in their surroundings declines, and it becomes

possible to improve the soundness of fuel with respect

15 to the driving of control rods during operation.

The advantages of the present invention will

be described below by taking a pressure tube type reactor

as an illustration.

Fig. 7 is a cross-sectional view taken along

20 the axis of a pressure tube 10 in the calandria tube 11

of a pressure tube type reactor. To facilitate comparison,

an array of conventional fuel rods 2 having the same

diameter is shown in the upper portion of the drawing,

while an array of fuel rods 1, 2 of the present invention

25 is shown in the lower portion thereof. In the central

portion of the drawing, the distribution of neutron flux

density in the case where the array of the conventional

fuel is used is shown by a dotted line B, while the

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1 distribution of neutron flux density in the case where
the array of the fuel of the present invention is used
is shown by a solid line A.

As can be appreciated from comparison between
5 the solid line A and the dotted line B in Fig. 7, as for
the fuel assembly arranged according to the present
invention, the decline of the thermal neutron flux density
thereof takes place gradually from the outer peripheral
zone to the central zone. In addition, there is no need
10 for the enrichment factor of fuel rods to be decreased
in the outer peripheral zone having a high neutral flux
density. Namely, it becomes possible to dispose a
greater volume of fissile material in the zone having a
high neutron flux density, thereby allowing the burn-up
15 degree of the fuel assembly to be improved without
increasing the local power output.

WHAT IS CLAIMED IS:

1. A fuel assembly for a nuclear ractor, adapted to be loaded in a reactor core and having a longitudinal axis with an outer peripheral zone surrounding said longitudinal axis and a central zone surrounded by said outer peripheral zone, said fuel assembly comprising a plurality of fuel rods extending along said longigudinal axis each of which has a predetermined fuel volume, said plurality of fuel rods including fuel rods that are arrayed in said outer peripheral zone of said fuel assembly and fuel rods that are arrayed in said central zone, wherein the fuel volume of each of said fuel rods disposed in said outer peripheral zone is smaller than that of each of said fuel rods disposed in said central zone.

2. A fuel assembly for a nuclear reactor, adapted to be loaded in a reactor core and having a longitudinal axis with an outer peripheral zone surrounding said longitudinal axis and a central zone surrounded by said outer peripheral zone, said fuel assembly comprising a plurality of fuel rods extending along said longitudinal axis each of which has a predetermined diameter, said plurality of fuel rods including fuel rods that are arrayed in said outer peripheral zone of said fuel assembly and fuel rods that are arrayed in said central zone, wherein the diameter of each of said fuel rods disposed in said outer peripheral zone is smaller than that of each of said fuel rods disposed in said central

zone.

3.   A fuel assembly for a nuclear reactor according to claim 2, wherein said fuel assembly has a plurality of central support rods disposed in said central zone.

4.   A fuel assembly for a nuclear reactor according to claim 2, wherein said fuel assembly for a reactor has a hollow cylinder with a diameter larger than that of said fuel rods disposed in said central zone as well as a port serving as an entrance and exit for a coolant at the upper and lower portions of said cylinder.

5.   A fuel assembly for a boiling water reactor, adapted to be loaded in the core of said reactor, said fuel assembly being divided into a plurality of groups surrounding one cross-shaped control rod and having a longitudinal axis with an outer peripheral zone surrounding said longitudinal axis and a central zone surrounded by said outer peripheral zone, said fuel assembly comprising a plurality of fuel rods extending along said longitudinal axis each of which has a predetermined diameter, said plurality of fuel rods including fuel rods that are arrayed in said outer peripheral zone of said fuel assembly and fuel rods that are arrayed in said central zone, wherein the diameter of each of said fuel rods disposed in said outer peripheral zone is smaller than that of each of said fuel rods disposed in said central zone, and the diameter of each of said fuel rods among those disposed in said outer peripheral zone which is disposed adjacent to said control rod is smaller than

that of fuel rods that are disposed in the other portion
of said outer peripheral zone.

6.   A fuel assembly for a pressurized water reactor,
adapted to be loaded in the core of said reactor, said
fuel assembly incorporating therein a plurality of control
rod guide pipes each accommodating a control rod, said
fuel assembly having a longitudinal axis along which
said control rod guide pipes are disposed and an outer
peripheral zone surrounding said longitudinal axis, said
fuel assembly comprising a plurality of fuel rods extend-
ing along said longitudinal axis, said plurality of fuel
rods including at least two types of fuel rods, comprising
at least a set of fuel rods having a large diameter and
another set of fuel rods having a small diameter, wherein
said small-siameter fuel rods are arrayed in said outer
peripheral zone of said fuel assembly and in the vicinity
of a position adjacent to said control guide pipes.
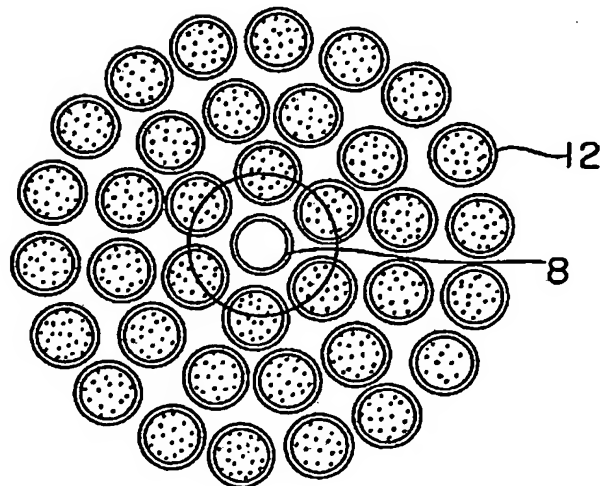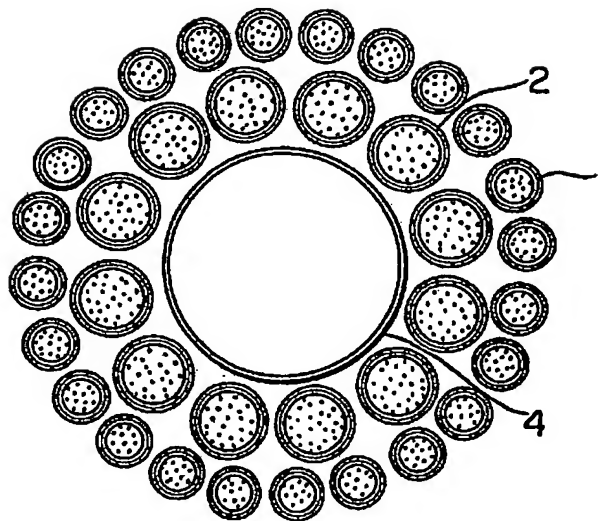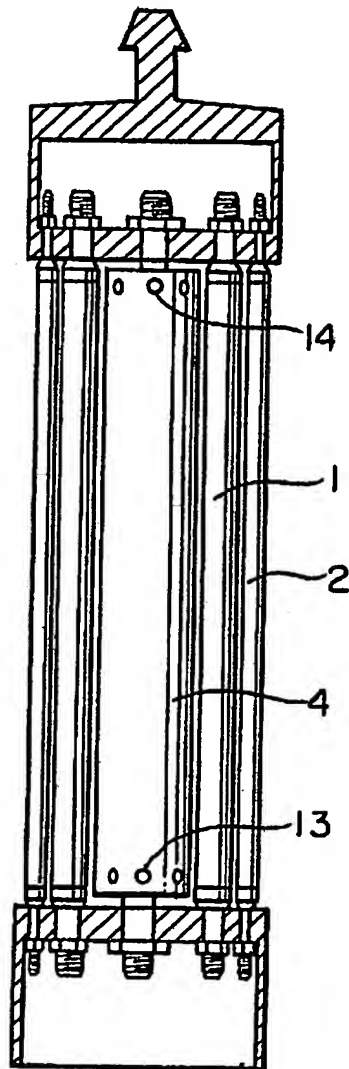
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FIG. I

FIG. 2

FIG. 3

FIG. 4

FIG. 5
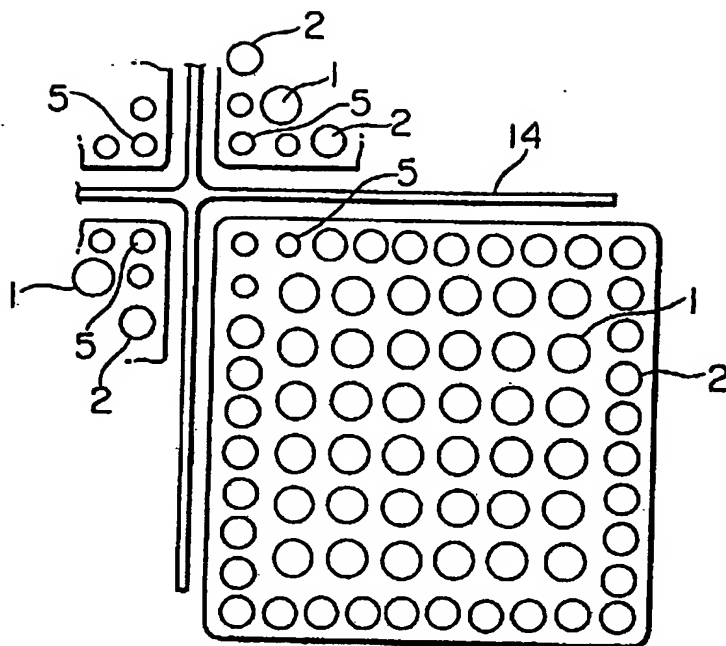
FIG. 6
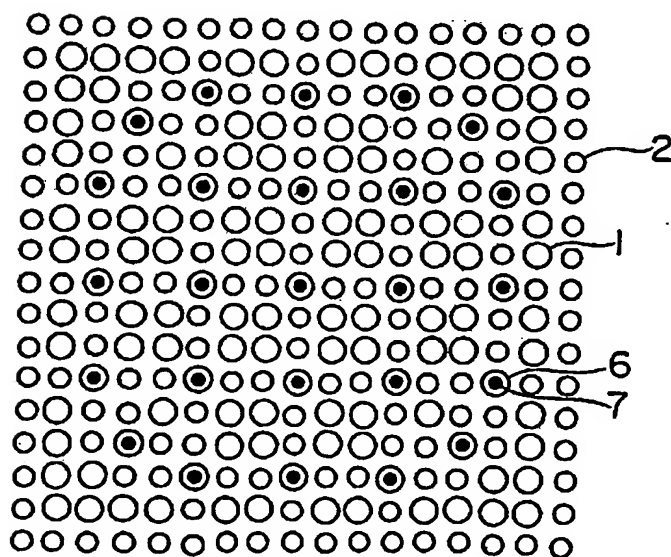
FIG. 7
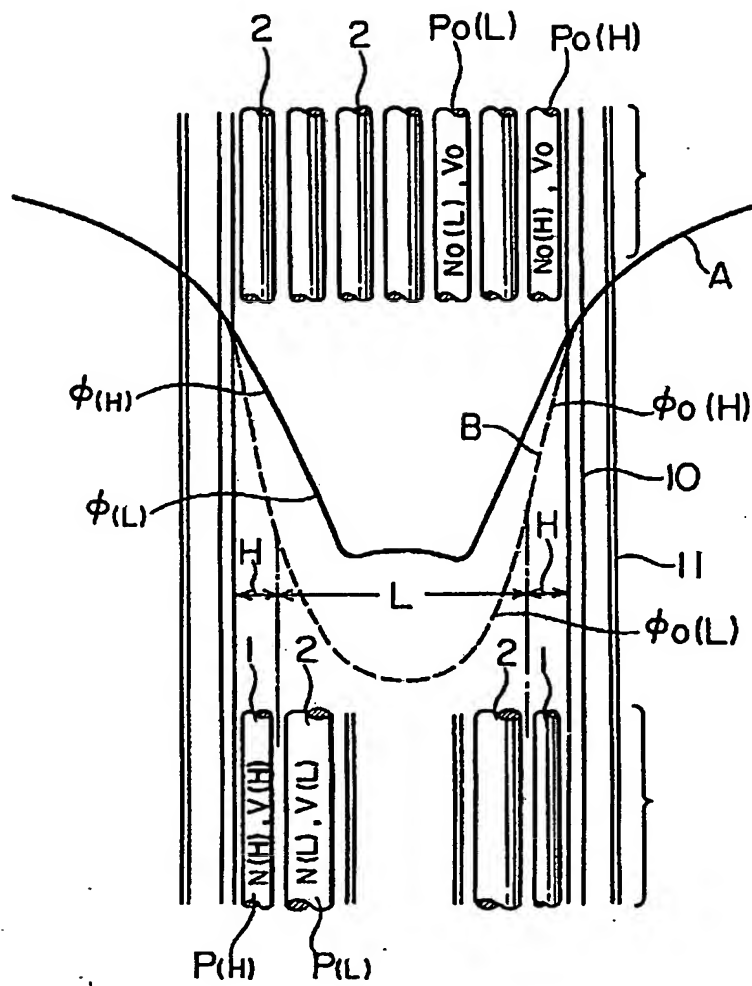
DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
X	FR-A-1 252 674 (SOCIETE NAT.D'ETUDE ET CONSTRUCTION DE MOTEURS D'AVIATION) * Page 2, right-hand column, lines 3-17; figures 5,6 *	1,2	G 21 C 7/00 G 21 C 3/32
D,A	US-A-3 132 076 (J.M. WEST et al.) * Column 3, line 71 - column 4, line 9; figure 5 *	1-3	
A	US-A-3 344 036 (R.J. HASLAM et al.) * Column 3, lines 3-12; figures 2,6 *	1-4	
A	EP-A-0 094 255 (WESTINGHOUSE) * Claim 1; figures 5,6 *	5,6	TECHNICAL FIELDS SEARCHED (Int. Cl.4) G 21 C 7/00 G 21 C 3/00 G 21 C 1/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	19-06-1986	ERRANI C.